Physical properties of tuffs from a scientific borehole at Alban hills volcanic district (central Italy)

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Introduction

- Recent seismic swarms and hydrothermal activity indicate that the Quaternary volcanic complex of Alban Hills may pose a threat to the city of Rome.
- A 350m scientific borehole was drilled (Fig. 1) in the south-western sector of the volcanic area, where seismic swarms, ground deformations and high gas concentration in water occur;
- The main goals of the drilling aimed to: 1) investigate the shallow crust structure; 2) estimate the present-day stress field and 3) install a broad-band seismometer at 200m of depth.

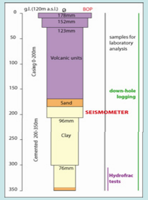


Fig. 1. Left - sketch of 350m borehole, including seismometer location. Right – Drilling operations (SO.RI.GE. Srl), carried out using wireline techniques (about 100% recovery)

Lithology

We have studied the physical properties of the pyroclastic units that are the most representative of the volcanic succession (Fig. 2) in order to compare to the field scale measurements and better understand the inner structure of the area investigated:

1) The 'Pozzolane Rosse' unit, a coarse-grained, extremely lithified facies, containing abundant mm-to-cm lava clasts and pyroxene and biotite crystals;

(2) The 'Tufo Pisolitico' unit). a fine-grained, matrix-supported pyroclastic deposit, with rare lithic lava clasts and sparse pumice and carbonatic clasts.

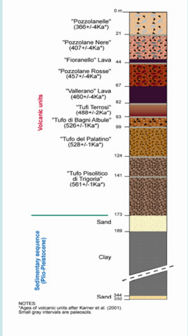
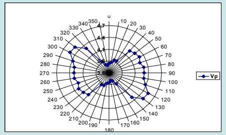


Fig. 2 – Volcanic and sedimentary units

Material characterisation

Elastic wave velocity measurements were performed at room pressure on cylindrical cores of 38 mm. Measurements were carried axially and radially (Fig. 4) at steps of 10°.

Pozzolana Rossa



Tufo Pisolitico

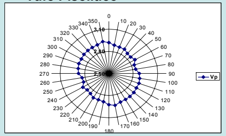


Fig. 4 – Radial Vp for Pozzolana rossa (left) and Tufo Pisolitico (right). An anisotropy up to 30% is found in the first case, due to the abundance of clasts in the matrix, while an isotropic behavior is observed for the Tufo Pisolitico controlled by the fine-grained matrix.

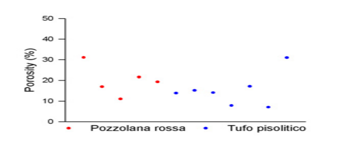


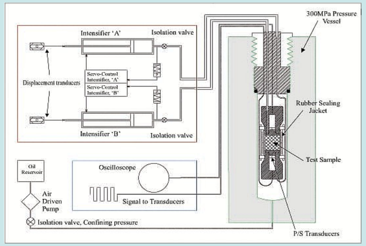
Fig.5 Initial porosity ranges about 10 – 30 %

Initial porosity (fig.5) was calculated after water saturation of samples:

$$\phi = \frac{(M_s - M_d)/\rho_w}{V_T} \cdot 100$$

Experimental investigation

Ultrasonic P and S wave velocity measurements and fluid permeability were carried out inside a fluid-medium hydrostatic pressure vessel. (Fig. 6). Measurements were made in a servo-controlled steady-state-flow permeameter at effective pressures from 5-80 MPa, during both increasing and decreasing pressure cycles.



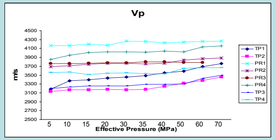
Sample

Pressure Vessel

Fig. 6: Schematic sketch of the servo controlled permeameter equipped for Vp, Vs measurements, sample set up and pressure vessel

Velocity measurements

P and S wave velocities carried out on fully water saturated samples (wet) confirm that the absolute Vp and Vs and the relative increase with increasing effective pressure are higher for Pozzolane Rosse. These patterns are compatible with the high litification and the abundance of lava clasts (Fig. 7) forming the Pozzolana Rossa microstructure.



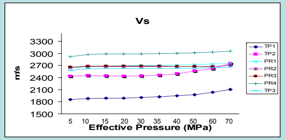
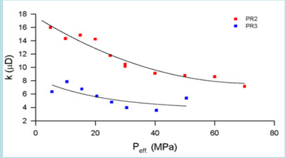


Fig. 7. P and S-wave velocity for Pozzolana Rossa (PR) and Tufo Pisolitico (TP) vs. Effective Pressure.

Fluid permeability show values in the range of micro Darcy for Pozzolana Rossa and spanning from milli to micro Darcy for the Tufo Pisolitico (Fig. 8), indicating that the two different mechanisms of emplacement have profound impact in the correspondent transport properties.



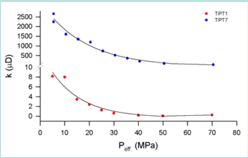


Fig.8. Fluid permeability for (left) Pozzolana Rossa (PR) and (right) Tufo Pisolitico (TPT) vs. Effective Pressure.

Velocity hysteresis

Significant velocity hysteresis is observed in the tuff (Fig.9). Both Vp and Vs are about 10% higher after depressurisation than before initial pressurisation.

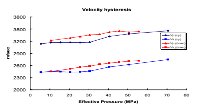
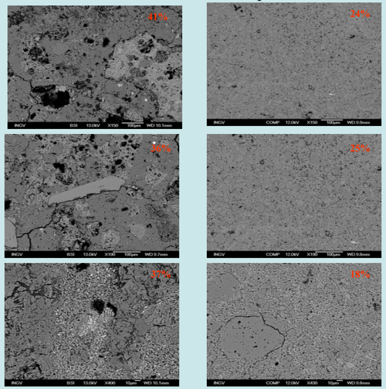


Fig. 9. Velocity vs. effective pressure. Permanent increase of velocity is originated from compaction due to pressurisation

Microstructural analysis

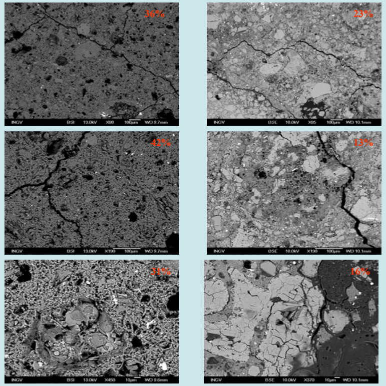
Pozzolana Rossa

Intact material | After pressurisation



Tufo Pisolitico

Intact material | After pressurisation



Ongoing microstructural analysis, by means of an innovative high-resolution thermal field emission scanning electron microscope, aims to clarify changes in the microstructure either due to pore collapse or crack damage before and after the pressurisation cycles.

Down-Hole Logs

Wire-line logs were performed (ICDP Operational Support Group, GFZ-Potsdam) in order to characterize the in situ physical properties of the volcanic rocks. Fig. 10 shows the evolution of compressional and shear wave velocities with depth. The sonic log was performed using a slim tool (Fig. 11) of 43 mm diameter, between 25 and 110 m.

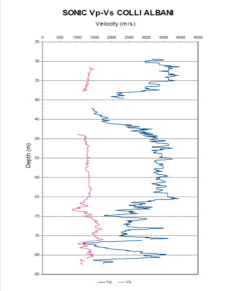


Fig. 10. Vp and Vs vs. depth. Velocities are in good agreement with lab samples measurements.

Fig. 11. Pulser-receiver system for sonic logs, with a "vertical resolution" of 50 cm and a "depth of investigation" between 20 and 70cm

Preliminary Conclusions

- Elastic wave velocities reflect the different mechanisms of emplacement and lithification.
- Fluid permeability is significantly affected from the different lithologies and increasing effective pressure;
- The comparison of down-hole and laboratory measurements is a reliable approach for strengthen our understanding of the inner volcanic district structure.

Future work

- *High temperature pore fluid effects and thermal damage (in collaboration with P. Benson and P. Young, UofT, Canada):*

Stress cycling damage and degradation of elastic moduli (in collaboration with M. Heap, S. Boon, UCL, London).